SUDBURY ENVIRONMENTAL STUDY

DETERMINATION OF THE EXTENT OF PARTICULATE STRATIFICATION AT THE INCO 381 M CHIMNEY AT COPPER CLIFF, ONTARIO.

SES 003/82

FALL 1982

Ontario
Ministry of the Environment

The Honourable
Keith C. Norton, Q.C.,
Minister

Gérard J. M. Raymond
Deputy Minister

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by

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01. SUMMARY

In February, 1980 a program to determine the extent of particulate stratification in the INCO 381 m chimney was executed jointly by MOE and INCO personnel. During the same test period, particle size and sulfuric acid determinations were attempted by the MOE sampling team.

Following the execution of a single unsuccessful test, the sulfuric acid determinations were cancelled due to low ambient and stack temperatures and a lack of available sampling time. On the basis of sulfate analyses of the particulate samples it is estimated that the sulfuric acid concentration in the stack gas was higher than 43 ppm.

Particle sizing tests were carried out using equipment designed in 1978 which collected both a size fractionated sample and a particulate sample on an in-stack filter. Particulate concentration comparisons between these two units did not agree as well as those determined in 1978; nevertheless, the three tests yielded particle mass median diameters between 6.4 and 3.3 microns. These data are compatible with sizing data collected at this site during past programs.

The particulate stratification determination consisted of four series of four individual tests, distributed among the four quadrants at the sampling location; one sample was taken at a single point while the other three were obtained at 20 points along the quadrant radii.

At the conclusion of the program, only two series of tests had been successfully completed. In these tests, particulate concentrations from individual samplings were significantly different, generally by a factor of two, thus confirming existence of particulate stratification at this source.

The mean particulate emission rate for the two acceptable test series was 436 g/s; $\pm$ 19.5g/s, in comparison to 355 g/s $\pm$ 48 g/s determined by single point sampling in 1977.

Emissions of trace species were generally within a factor of two of the 1977 mean. The mean emission rates of selected trace species for the two acceptable test series were 12.4 g/s for copper, 12.3 g/s for nickel, 40.7 g/s for iron and 1.32 g/s for arsenic.

Process data collected by INCO personnel over the test period included information on the efficiency of the Cottrell electrostatic precipitation units. While a simple direct relationship between process operating parameters and emissions could not be formulated, the operating efficiencies of the precipitators were lower than would be anticipated from the results of previous sampling programs at this source (1) or from the published information (3,4). Unfortunately, no similar process data from the past programs at this site are available, hence no comprehensive analysis of emission and production data could be made. The fact that the stack gas temperatures were lower and sulfuric acid in the stack gases may have been condensed suggests that the process was not the same as in the past; the lower temperatures

were the result of removal of one of the four reverberatory furnaces and associated equipment from the nickel circuit.

02. CONCLUSIONS

1. Particulate concentrations and emissions from individual tests indicate the existence of particulate stratification at the sampling location. The stratification profile changes with time, thus the possibility of finding a sampling point where the particulate emission is representative of the average-across-stack emission is minimal.

2. In the two acceptable series of simultaneous samplings, the single-point tests yielded the lowest particulate concentrations and emissions. In comparison with the average values obtained from all four individual tests, the particulate emissions from single-point tests were lower by about 21% and 60%. These percentages are presently the best available estimates of errors associated with single-point sampling.

3. Average emissions of particulates from the two acceptable test series were 436 $\pm$ 19.5 g/s, about 23% higher than 355 $\pm$ 48 g/s measured at a single point in 1977. However, considering the errors associated with single point sampling, it is not certain whether this increase in emissions is significant.

4. Mean emissions of trace metals were generally within a factor of two of the 1977 means. Nickel emissions at 12.33 g/s were about 34% higher this year, iron and copper emissions at 40.7 g/s and 12.35

g/s respectively were almost identical to those in 1977, while emissions of zinc at 1.66 g/s, magnesium at 1.18 g/s and chromium at .47 g/s were lower this year. Somewhat suprisingly, the concentration and emission profiles of trace metals across the stack cross-section were different from those of particulates and, in most cases, single-point sampling did not produce the lowest values.

5. While no specific testing for sulfuric acid was performed, sulfate analyses of the samples collected in both isopropanol and water impinger solutions suggest that the acid concentration is in the vicinity of 43 ppm or higher at the sampling location. These concentration data correlate well with the aerosol formation temperature in the stack gases.

6. The particle sizing tests, while subject to some sources of error, yielded distributions with mass median diameters between 6.4 and 3.3 microns. These values are comparable to others derived at this site in previous sampling programs but somewhat higher than at other smelters (3,4). The magnitude of the mass median diameters suggests that at least some of the electrostatic precipitators may not have been operating to design efficiency, and operating data submitted by INCO on these units confirm that this was the case.

7. Process data and precipitator operating data confirm that varying electrostatic precipitator efficiencies have a significant effect on particulate emissions. Since the available information was still not adequate to formulate a direct correlation between process operating

data and emissions, further attention should be given to determining precipitator efficiencies in any future test programs.

03. RECOMMENDATIONS

1. Because of particulate stratification at the sampling site, multipoint sampling in the 321 m chimney may have to be required in rigorous emission measurements, such as compliance sampling; except when the emissions of any particulate pollutant of interest measured at one or more sampling points are severalfold lower than a predetermined acceptable minimum.

2. For lack of better estimates, possible errors in emissions due to single point sampling in the past programs at this stack could be estimated from this year's results; hence all emissions based on single-point sampling may have been underestimated by as much as 60%.

3. Single-point sampling may be acceptable in future programs where a probable range, rather than a fixed value of emissions of particulate pollutants is acceptable.

04. OBJECTIVES OF SAMPLING PROGRAM

Since the construction of the smokestack was completed in 1972, sampling for particulate and trace elements at the INCO 381 m chimney has been performed using a number of procedures. Generally, a great majority of these sampling programs used an EPA method 5 type particulate sampling train to determine emissions of particulate

matter and trace elements. However, given the 13.7 m diameter of the chimney and the proximity of the sampling location to the inlet breeching - approximately four stack diameters - it was uncertain what procedures were appropriate for obtaining a representative particulate sample at this source.

Initial sampling programs were carried out in 1973 under the direct supervision of the Air Management Branch, Ministry of the Environment. During these tests, a sampling grid consisting of 88 points distributed along two complete traverses of the chimney was used. Execution of these tests was difficult due to the cumbersome nature of the equipment, in particular the 7 m long probes, and the extensive time required for completion of a single test. Sampling times in the vicinity of 12 to 14 hours were not uncommon, resulting in some hardship to crews working at the relatively inaccessible sampling site.

Following the 1973 program, attempts to demonstrate that the particulate concentration profile across the chimney at the sampling level was uniform by simultaneously sampling at a single point within the cross-section of the chimney and at a number of points in other segments of the cross-section were made (5, 6). However, the data from these test programs did not clearly indicate that the homogeneity of the particulate concentration across the stack was existent.

In ensuing years, particulate sampling was performed at a single location to collect emission data in conjunction with the Sudbury Environmental Study airborne plume sampling program. On reviewing

all available emission data, significant variations in particulate and trace metal emissions were noted. These variations were partly due to process changes, but also they could have been a result of nonrepresentative one-point sampling in a stratified particulate flow. It was therefore concluded that an attempt should be made to determine if particulate stratification was significant at this source.

Measurements of sulfuric acid emissions and particulate size distributions were also planned, to complement particulate emission data and to provide an update on emissions from the Inco 381 m chimney.

05. ACID AND PARTICULATE TESTING

05.01 Acid Emissions

It was originally planned to determine sulfuric acid emissions using a procedure applied at both this and similar sources in recent years. Essentially, a gas sample was to be taken at a single sampling point using a modified EPA method 5 train. Modifications to this train would include a teflon lined probe, use of quartz fibre filters both in front of the impingers and between impingers #2 and #3 and replacement of the distilled water in the impinger train with an 80% isopropyl alcohol in water solution.

On arrival at the site, it was found that process modifications had reduced the stack gas temperatures to such an extent that formation of

an aerosol was observed in the gas stream at the sampling level on occasion. In subsequent particulate testing, temperatures at the rear of the probe in the sampling train were frequently below 121° C, which was unacceptable for acid testing. Given that the procedure was designed to vaporize sulfuric acid in the front portion of sampling train, that ambient temperatures were too low to permit adequate heating of the apparatus and that unforeseen delays had been encountered in the particulate segment of the program, it was decided that acid sampling would be eliminated from the program.

05.02 Particulate Emissions

05.02.01 The Sampling Program

The extent of particulate stratification in the gas stream of the 381 m chimney was determined by simultaneous sampling in four quadrants using particulate sampling trains as required by the Ontario Source Testing Code. Three of these trains were used to sample at twenty points along radii in three quadrants while sampling with the fourth train was done at a single point in the fourth quadrant. Personnel from the Air Resources Branch and the Northeastern Region operated two of the three multipoint sampling trains; the third multipoint train and a single point unit were operated by INCO personnel. The arrangement of the sampling trains is shown in Figure 1; note that the GII-N unit is offset from the centre of the north semicircle. This offset permitted sampling in a heated, enclosed room already available on site.

The particulate test series was to consist of three acceptable simultaneous sampling tests. An individual test would be considered acceptable if three of the four sampling trains functioned satisfactorily throughout the sampling period. Particulate samples would be recovered from the trains and particulate concentrations derived from each train compared to determine the extent of particulate stratification. However, only two test series were successful while one was invalidated, in part by non-isokinetic sampling at two quadrants.

05.02.02 Particulate Emission Determination

Because of low ambient temperatures encountered in the execution of the program, the three multipoint sampling trains used isopropyl alcohol rather than water in their impingers to avoid any possibility of freezing these solutions; consequently the stack gas moisture content was not determined in these tests. The single-point sampling train used water in impingers and all moisture data were taken from this train. The single-point train also included a frit made of stainless steel instead of glass.

Table 1 summarizes values of various stack gas sampling parameters collected during the particulate program. During the first test period, two sampling units malfunctioned and thus only data from the other two units are given. The sampling trains were identified as GII-N, and JOY-E, RAC-S and GII-W; and as shown in Table 1, the GII-N and

JOY-E trains were operating subisokinetically during both test #2 and test #3, due to improper nozzle size selection. As a result, particulate and trace element emissions data from those two units during these tests are not representative, and probably overestimate the true values.

During the test program, the lower stack gas temperatures, brought about largely by elimination of one of four reverberatory furnaces in the nickel circuit, may have resulted in acid aerosol formation and degradation of the chimney's mild steel liner. Low temperatures persisted through test #2, and while recovering samples from the trains at the conclusion of the test, the presence of very large particles was observed. Deposition of similar sized particles from the plume was also observed within INCO property during the test period. Because of the presence of these large particles, which may have been formed as a result of acid aerosol attack on the chimney liner, this year's test conditions and data should be considered as different from those collected in previous years.

In addition to a gas temperature variation from quadrant to quadrant, variations in gas velocities were noted in each quadrant. As a result, overall stack gas volumetric flow, as determined from these velocities, varied as well. In tests #3,#4 and #5, velocities were highest in the east quadrant and lowest in the south. However the particulate concentrations do not follow this velocity trend, contrary to a common misconception that faster segments of a gas stream must carry more particulates. Velocity data from the GII-N unit for all tests are not comparable since they were collected at a single point; data from JOY-

E unit collected during test #2 were also collected largely at a single point.

Table 2 summarizes particulate and individual species concentration data collected during the sampling program. Note that data are not given for the GII-N and JOY-E trains in test #2, since these units malfunctioned during testing. Limited data are given for test #3 because of the isokinetic error mentioned previously. These particulate values are included for comparative purposes only.

The term 'particulate' is used in this report as it is defined in the Ontario Source Testing Code, i.e. as material collected in the probe and filter of the sampling train when these two units are operated at 121° C. It has been demonstrated in the past that particulate samples from this site include some sulfate material, and given the substandard temperatures prevailing in at least some segments of the probe and the intermittant aerosol formation observed in the stack gas, sulfate material continued to be a significant fraction of the particulate sample. In performing analyses of the probe wash, isopropanol soluble sulfates were determined following filtration. These sulfates were added to the filter residue to determine the particulate catch in the front end.

Due to sampling errors in tests #2 and #3 and the unrepresentative nature of the conditions prevelant during test #2, only test #4 and test #5 are of acceptable quality for determining the extent of particulate stratification in the stack gas. In test #4, the spread between the highest and lowest value of the particulate concentration in individual

quadrants is approximately a factor of two; the spread among concentrations derived during test #5 is less than two. It is interesting to note that testing at the single point location in the north quadrant yielded the lowest particulate concentration in both tests #4 and #5.

Table 3 gives particulate and trace elements emission rates derived from the sampling program. In several cases, particulate emission rates for individual tests were greatly in excess of the mean value of 355 g/s, determined in 1977 by single point testing in the south quadrant. The mean of tests #4 and #5 was 436 g/s and the accompanying standard deviation was 111.4, representing about 25% of the mean. Differences between minimum and maximum individual values in the two test series were by a factor of 1.65 and 2.

Particulate stratification is implied by the particulate concentrations determined from these programs. In both instances, as shown in Table 2, particulate concentrations determined in the north quadrant were lowest of the four, although no consistent pattern emerged among the balance of the concentration data. This result suggests that sampling at a single point in the north quadrant could yield data which underestimate the particulate emissions from this source. It also suggests that the particulate stratification profile changes with time, hence no fixed representative quadrant or single-point can be found at this sampling location.

05.02.03 Trace Species Emissions

As shown in Table 2, the ranking established in tests #4 and #5 for the particulate concentrations from highest to lowest is not applicable to emissions of the principal species present. However, with the exception of iron in test #5, copper, nickel and iron show a consistent ranking from test #4 to #5. Samples taken in the east quadrant were highest in these species, followed by samples from the north quadrant, the south quadrant and the west quadrant in that order. In the case of iron in test #5, the concentration determined in the south quadrant was highest, followed by the north, east and west. This ranking will be explored in more depth in the segment of the report dealing with the effect of process variations on emissions.

A comparison of emission concentrations of relatively volatile metals reveals some inconsistencies. Variations in the emission concentrations of lead and cadmium obtained at the four locations were insignificant in both tests #4 and #5 . However, arsenic shows significant variation with location; while not identical to those seen for iron and nickel, this variation is consistent from test to test.

As noted previously, acid testing was not performed during this program; however isopropanol was used in the impingers of three of the four trains during the sampling. Table 2 gives the concentration both of IPA soluble sulfate and total sulfate. The mean of the IPA soluble sulfate concentrations is equivalent to 25 ppm, and the mean of the total sulfate concentration is 40 ppm. If these concentrations are considered

as sulfuric acid in a gas stream with 2% moisture, the corresponding acid dewpoint is estimated as between 130 and 136° C. These data show some correlation with observed aerosol formation in the stack gas.

Comparing trace species emission rate data from tests #4 and #5 to the 1977 mean, most values are within a factor of two of that mean. Two of the more volatile species, lead and cadmium, were consistently more than a factor of two above the 1977 value for all sampling in test #4, and a number of aluminum emission rates were in excess of the 1977 mean. Possible correlations with process activity will be explored in a subsequent section of this report.

06. PARTICLE SIZING

Particle size determinations were performed at the source using an Andersen MK III cascade impactor with glass fibre filter substrates. The apparatus used was similar to that developed during a sizing program in 1978, in that it included an additional nozzle and probe with Balston in-stack filter to provide comparative data on total particulate emissions.

Table #4 summarizes average values of the stack sampling parameters determined during the particle size sampling. The first pair of tests, AND #1 and Balston #1, were both slightly superisokinetic, and as shown in Table 5, particulate concentrations as derived from the two procedures varied by more than a factor of two. A somewhat smaller deviation in concentrations was noted for the second pair of tests, in

spite of more acceptable isokinetic data. The third pair of tests had comparable particulate concentrations but the Balston sampling was more superisokinetic. The mass median diameter determined from this test was 6.4 um; the same value was obtained during the first test. The second sizing test yielded a value of 3.3 um. The spread of this sizing data compares well with the conclusion from the 1978 sizing program (2) that particulate emissions from this source have a mass median diameter between 3 and 6 microns. Data on the size distribution are given in Tables 6, 7, and 8 and Figures 2, 3 and 4.

While it was anticipated that particulate concentrations determined from the cascade impactor catch would be somewhat lower than those derived from the Balston unit, due to the higher possibility of incomplete sample recovery from the Andersen unit, it is unlikely that the deviations in particulate concentration between these two types of sampling seen in tests #1 and #2 can be attributed entirely to this factor. However, it should be noted that a gravimetric determination was performed on the cascade impactor front end and internal washings and glass fibre substrates only; loadings from all jet plates, crossbars and space ring washers were not determined gravimetrically. In the first two tests of the series, significant deposits were noted, particularly on the jet plate preceding the glass fibre substrate on stage one. Thus, materials recovered from this segments of the impactors could account for the difference between the two units.

Emission concentrations and rates for individual species are given in Table 9, along with mean values determined during 1977 particulate

sampling. These data are not comparable in quality to the particulate data and are presented for purposes of comparison only. Again, a great majority of the emission rates is within a factor of two of the 1977 mean.

Analysis for total sulfate was also performed on samples from the sizing program and the concentration of this material, if considered to be sulfuric acid, lies between 36 and 43 ppm. This spread is in reasonable agreement with similar values determined from the particulate program, given that some of the sulfate detected in the Andersen impactor is undoubtedly due to a spurious formation resulting from the interaction of sulfur dioxide and the glass fibre impaction substrates.

The particle sizing testing, while subject to some sources of error, yielded distributions with mass median diameters between 3.3 and 6.4 microns. These values are comparable to those derived during the 1978 sizing program at this source (2).

07. EFFECT OF PROCESS VARIATIONS ON EMISSIONS

Table 10 summarizes process data collected by INCO personnel over the test period. Included are mean particulate concentration data determined from the four test series. Note that the mean values given for tests #2 and #3 are based on two tests only.

The process information submitted by INCO included some estimation

of individual precipitator efficiencies expressed as a percentage. These data are shown in Table 11. No information on the procedures used to determine these efficiencies is given and the fact that the same data are given for test #2, #3 and 4 suggests that they may be approximate values. No operating data were submitted for the fluid bed roaster precipitation units.

In reviewing the information given in Table 11, it is clear that the particulate emission rate estimates given as part of the precipitator information are significantly lower than the rate determined by source testing. There is a possibility that this difference may be partially due to different sampling procedures used at the precipitators and the stack; for example, the precipitator outlet sample may have been expressed on the basis of 'dust' loading, excluding any sulfates caught with the dust. Another possibility is that samples may have been obtained at locations where the sample gas temperature was high enough to allow all sulfuric acid to pass in the vapor state through the collection medium.

Data given in Tables 10 and 11 suggest that Cottrell efficiencies vary significantly over short periods of time and that variations in Cottrell performance have at least as much impact on emissions as do variations at individual processes. Generally, with the exception of Cottrell precipitator #2, which cleans gases from nickel convertors #2 through #10, the balance of the precipitators operate at efficiencies of 90% or

better, except for precipitator #3 where an efficiency of 84% was reported during test #5. As mentioned, these data are very approximate, but the variations in efficiencies demonstrated by them suggest that more stringent and frequent testing of these units may be warranted.

Comparing the particulate and trace species concentrations with process information given in Table 10, the highest mean particulate concentration corresponded to maximum copper convertor blowing time, as well as maximum blister copper production and fluid bed roaster input. The roaster-reverb circuit appeared relatively stable over the entire test period as reflected by the relatively constant roaster concentrate feed and reverberatory furnace slag disposals. Only during test #4 was reverb slag production markedly higher.

The mean particulate emission concentration for test #2 was the second highest of the series; nevertheless, the process parameters collected indicated a comparatively low level of activity, significantly lower than during test #4 or #5. These comparisons are crude because the process data are frequently collected over 8 or 24 hour periods, while the test period was typically between 3 and 4 hours. Also, the precipitator data given in Table 11 do not indicate a major change in the overall loading to the chimney between test periods #2 and #3, in obvious disagreement with stack testing data. Since the stack testing data may be considered more representative, the method used for estimation of precipitator efficiencies should be reviewed in an attempt to explain this discrepancy.

Similarly, while the mean particulate concentrations for tests #4 and #5 are comparable, as are particulate emission rates estimated from the precipitator efficiency data, the process data show that the fluid bed roaster was nonoperational during test #5. Other areas of the process did not show such dramatic variations, which does suggest that process and precipitator operational data are not precise enough to formulate accurate process/emission correlations.

Information on the percentage of copper, nickel and iron in the dust from various processes, included in the INCO process data and given in Table 12, was used along with precipitator operating data to estimate emission rates of these metals. Emissions from #3 Cottrell precipitator were estimated based on a percentage analysis of precipitator dust previously filed with MOE. These estimates are presented in Table 13, along with the mean element emission rates as determined by source testing. Given the approximate nature of the precipitator data, the agreement between the estimated value and the actual value is, in test #5, reasonably good. Poorer agreement for nickel in tests #1 and #2 could be partly due to incompleteness of stack testing data. Data are not presented for tests #3 and #4, since precipitator operating data given for test #2 were applied to these test periods.

The process and precipitator operating data collected over this testing program, while not precise enough to allow formulation of an accurate correlation between emissions and process operations, confirm the impact of varying precipitator operation on emissions. The data

indicate that some of these units operated at less than 90% efficiency and efficiencies as low as 51% have been reported. These low efficiencies suggest that the particulate mass median diameter of 6.4 um, repeatedly observed at this source, could be an accurate reflection of non-ideal precipitator operation.

LIST OF REFERENCES

1. Acid, particulate and particle sizing at INCO Superstack June 1977, Ministry of the Environment, Toronto, Ontario, Report No. ARB-TDA 55-78, February 1978.

2. Particle size determinations at the 381 m chimney, INCO smelter, Copper Cliff, Ontario, Ministry of the Environment, Toronto, Ontario, Report No. ARB-TDA 43-80, June 1980.

3. Study of factors affecting the electrostatic precipitation effeciency of particulates in non-ferrous smelter gases, July 1979 H. J. Davis, J. D. Kerbyson, D. C. Nethorsole, Centre De Recherche Noranda, Pointe Claire, Quebec.

4. Trace element study at primary copper smelter, Radian Corporation, Austin, TX, March 1978, NTIS PB - 286991.

5. Superstack Emissions Monitoring 1974 Campaign - Comparison of Single Versus Multi-Point Sampling, INCO, Process Technology Project No. 047.6, March 10, 1975.

6. Superstack Emissions Monitoring 1975 Campaign - Comparison of Single Versus Multi-Point Sampling, INCO, Process Technology Project No. 047.10, April 14, 1976.

7. 380 m Chimney Emissions Monitoring - 16 Particulate and Acid Determinations
(July - October, 1979), INCO, Process Technology Project No. 047.17, December 18, 1979.

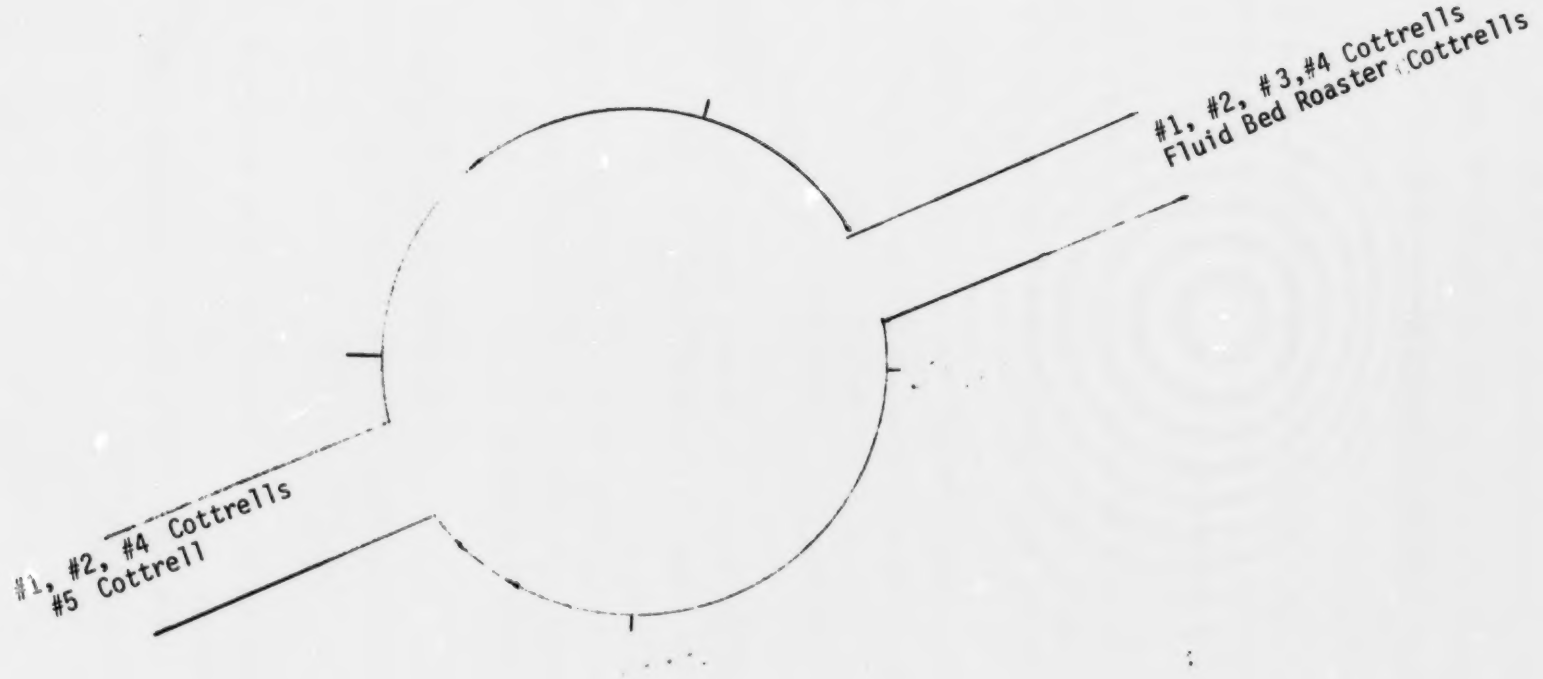

FIGURE 1: INCO 380 m Chimney Cross-Section and Inlet System (not to scale)

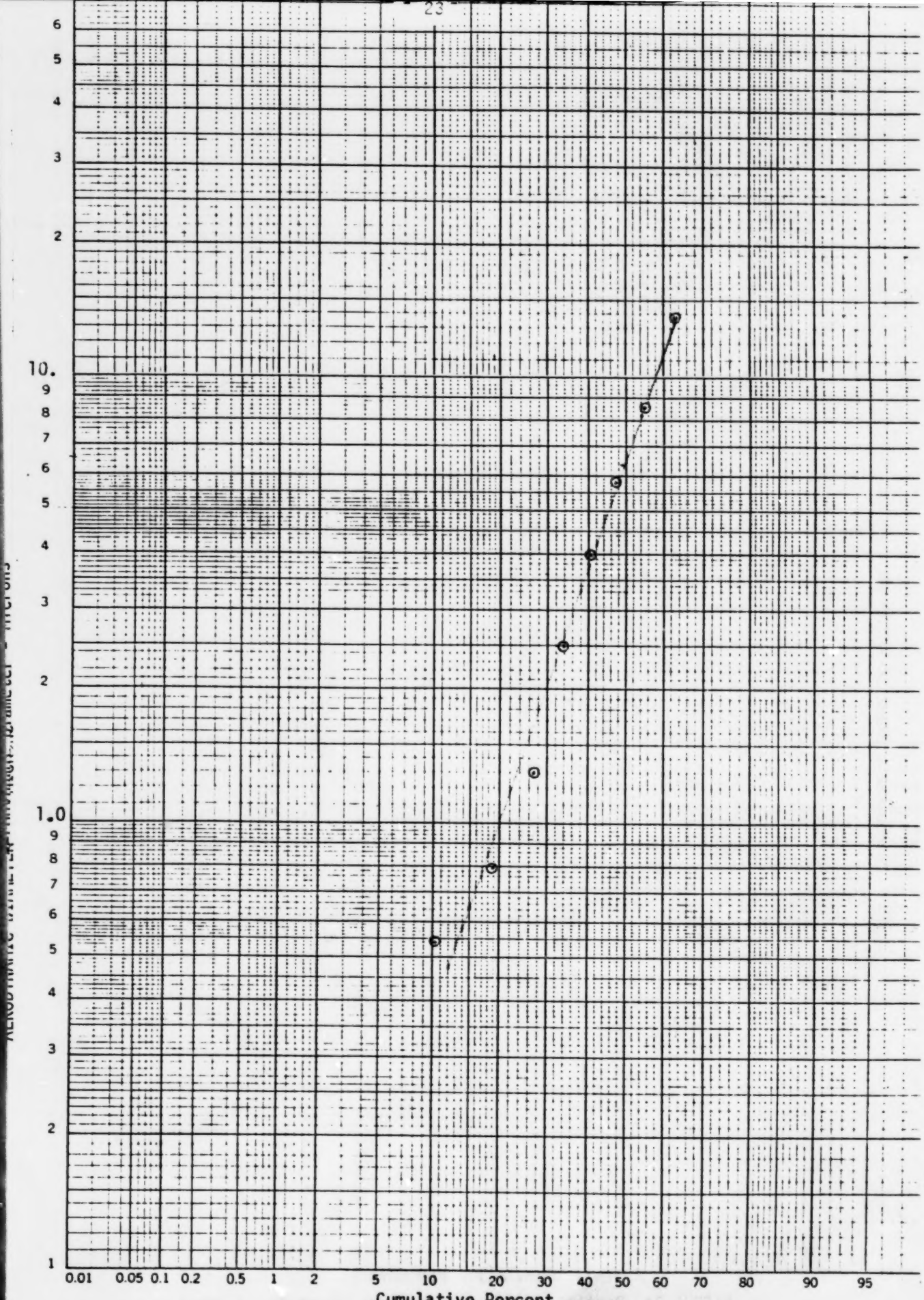

FIGURE 2: Particle Size Distribution - Test #1

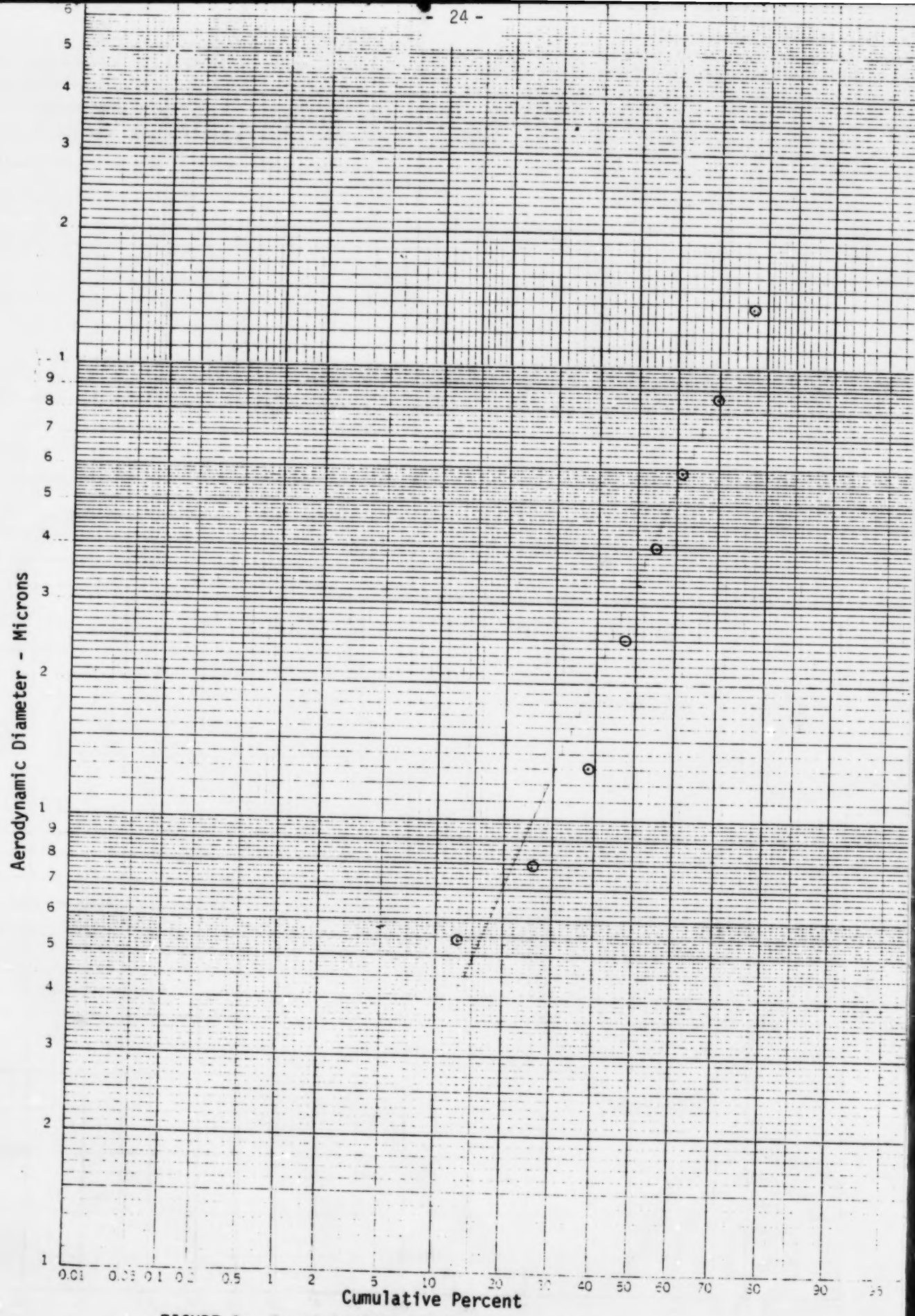

FIGURE 3: Particle Size Distribution - Test #2

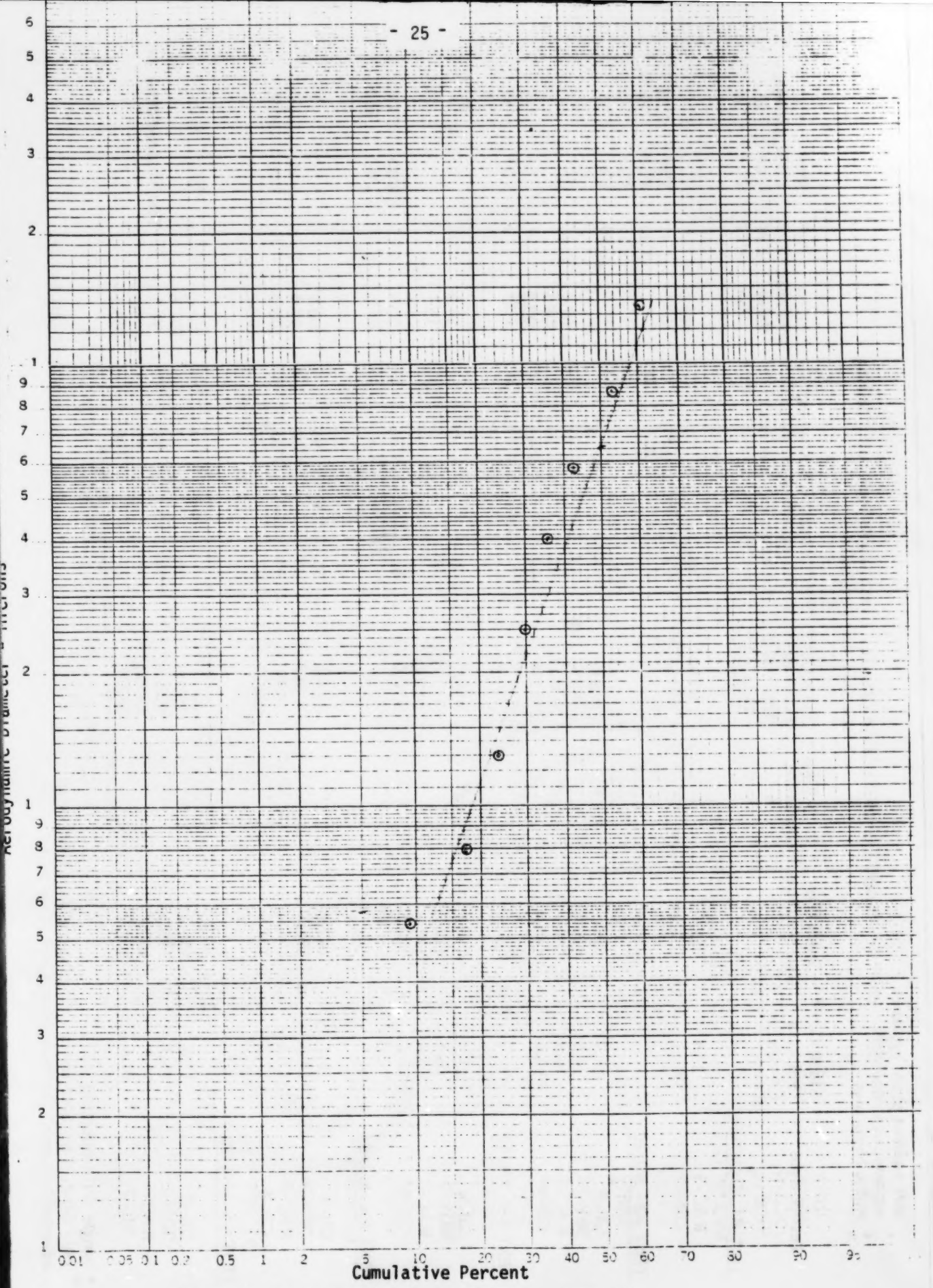

FIGURE 4: Particle Size Distribution - Test #3

TABLE 1: INCO 381 m Chimney - 1980 Single/Multipoint Testing
Stack Sampling Parameters

Test & Date	Stack Gas Velocity m/s	Stack Gas Temperature °C	Stack Gas Moisture %	Stack Gas Flowrate DSCMM	% Readings Within ±10% Isokinetic	% Readings Within ±15% Isokinetic	Mean Isokinetic Value %	Comments
Test #1 31/1/80								
RAC-S	22.4	137+	2	134000	85	90	104.5	
GII-W	14.7	132.	2	90164	72	90	104.9	
TEST #2 5/2/80								
GII-N*	13.7	100.	2.13°	90814	0	0	60.25	
JOY-E*	14.9	100.8		98856	17	21	69.1	
RAC-S	16.9	115.+		103800	82	90	106.8	
GII-W	15.0	148.3		88516	92	98	103.0	
TEST #3 7/2/80								
GII-N*	13.8	134.7	3.18°	83322	0	0	56.9	
JOY-E	16.3	127.3		101000	0	0	58.1	
RAC-S	13.6	148.+		79500	72	77	106.6	
GII-W	15.6	132.7		95410	92	95	102.5	
TEST #4 8/2/80								
GII-N*	14.1	142.9	2.07°	84541	95	98	100.2	
JOY-E	15.6	128.8		97065	97	98	99.9	
RAC-S	13.2	144.+		76000	93	93	105.2	
GII-W	15.3	131.6		94678	97	100	102.7	
TEST #5 11/2/80								
GII-N*	13.6	139.8	2.23°	80003	97	97	101.6	
JOY-E	15.3	131.3		92221	94	96	98.5	Test stopped after 141 mi
RAC-S	12.9	130.+		74900	92	93	103.5	
GII-W	14.6	139.0		86282	97	100	103.1	

* single point sampling
° only GII-N train used water in impingers; data from other trains were adjusted to correspond to this moisture percentage.
+ adjusted to correct for bias determined after test.

TABLE 2: INCO 381 m Chimney - 1980 Single/Multipoint Testing
Emission Concentration of Individual Species
g/DSCM

Test & Date	Part. $x10^{-1}$	H_2SO_4 $x10^{-2}$	$SO_4^=$ $x10^{-1}$	Cu $x10^{-3}$	Ni $x10^{-3}$	Co $x10^{-4}$	Fe $x10^{-2}$	Pb $x10^{-3}$	Cd $x10^{-4}$	Zn $x10^{-4}$	Mg $x10^{-3}$	Mn $x10^{-5}$	Al $x10^{-3}$	Cr $x10^{-4}$	As $x10^{-3}$
#1, Mar.31															
RAC-S	N/A			2.11	.97	.47	.4	4.0	2.7	5.63	.18	2.67	1.53	2.00	N/A
GII-W	N/A			2.61	1.17	2.9	.56	3.6	3.7	4.21	2.6	3.60	2.44	1.77	N/A
#2, Feb. 5															
RAC-S	4.39	7.88	1.73	10.8	20.6	7.02	5.94	4.93	5.09	8.5	2.23	20.9	4.41	7.49	.818
GII-W	4.01	10.3	1.56	4.28	6.93	2.52	2.41	3.52	3.65	6.3	1.07	9.5	2.62	6.05	.72
#3, Feb. 7															
GII-N°*	1.98	6.01													.76
JOY-E*	2.46	8.31													1.14
RAC-S	5.88	10.6	1.52	5.66	5.26	1.12	1.86	4.65	2.60	8.42	.747	5.81	1.15	2.24	1.32
GII-W	4.78	11.9	1.54	4.39	3.62	1.33	1.31	3.74	2.16	5.50	.508	5.78	.94	4.04	1.38
#4, Feb. 8															
GII-N°	1.92	11.4	1.65	10.1	7.77	2.71	3.10	8.75	5.93	11.6	.772	6.52	1.89	2.9	.77
JOY-E	2.77	10.3	1.86	10.7	11.20	4.03	3.41	9.09	5.87	12.4	.89	7.05	5.23	3.59	1.17
RAC-S	4.03	10.5	1.65	7.79	6.19	2.09	2.47	8.72	5.61	12.5	.80	5.76	2.39	4.28	.63
GII-W	3.68	8.63	1.23	4.99	3.39	14.7	1.27	7.31	5.09	10.6	.47	3.82	1.57	2.86	1.28
#5, Feb. 11															
GII-N°	2.46	8.82	1.52	10.3	12.3	3.97	3.49	4.78	3.62	14.3	1.05	7.77	5.35	3.54	.74
JOY-E+	3.52	13.3	2.83	10.4	12.5	3.96	3.39	4.98	3.43	13.3	1.25	12.4	5.64	3.86	.97
RAC-S	2.73	7.14	1.15	9.31	10.6	3.46	4.15	4.52	3.44	8.37	.62	5.37	2.50	1.88	.54
GII-W	3.16	10.7	1.39	5.37	4.9	1.80	1.64	4.26	2.92	9.33	.70	5.23	4.76	2.96	1.12

° single point test
* subisokinetic sampling - emission data unrepresentative
+ test stopped after 141 min.

TABLE 3: INCO 381 m Chimney - 1980 Single/Multipoint Testing
Emission Rate of Individual Species
g/s

Test & Date	Part.	H_2SO_4	SO_4	Cu	Ni	Co	Fe	Pb	Cd	Zn	Mg	Mn	Al	Cr	As
**1977 Mean	355			11.42	9.22	.34	39.4	4.89	.38	2.96	1.53	.08	2.54	.62	
++ 1980 Mean	436			12.35	12.33	.68	40.7	9.47	.65	1.66	1.18	.10	5.32	.47	1.32
#1, Jan. 31															
RAC-S				4.36	2.0	.097	8.49	8.32	.56	1.2	.37	.06	3.16	.41	N/A
GII-W				3.93	1.76	.443	8.48	5.38	.55	.63	.38	.05	3.67	.27	N/A
#2, Feb. 5															
RAC-S	774.5	139.	307.	19.1	36.6	1.24	105.	8.7	.90	1.50	3.95	.37	7.8	1.3	1.45
GII-W	592.1	152.	229.	6.3	10.2	.37	36.	5.2	.54	.93	1.60	.14	3.9	.89	1.06
#3, Feb. 7															
GII-N°*	274.5	84.													
JOY-E*	416.0	140.													
RAC-S	795.2	143.	206.	7.65	7.11	.15	25.2	6.28	3.51	1.14	1.01	.079	1.56	.30	1.78
GII-W	761.7	189.	245.	6.99	5.75	.21	20.9	5.95	3.44	.88	.81	.092	1.49	.64	2.19
#4, Feb. 8															
GII-N°	270.7	161.	232.	14.3	10.9	.38	43.7	12.3	.84	1.64	1.09	.092	2.67	.41	1.08
JOY-E	447.7	166.	302.	17.4	18.1	.65	55.1	14.7	.95	2.01	1.44	.114	8.46	.58	1.90
RAC-S	522.0	135.	214.	10.0	8.0	.27	31.9	11.3	.73	1.62	1.04	.075	3.10	.55	.81
GII-W	581.6	136.	195.	7.88	5.4	2.3	20.0	11.5	.80	1.68	.74	.06	2.48	.45	2.02
#5, Feb. 11															
GII-N°	326.4	117.	203.	13.7	16.4	.53	46.5	6.38	.48	1.91	1.40	.10	7.14	.47	.99
JOY-E+	539.3	205.	435.	15.9	19.3	.61	52.1	7.66	.53	2.04	1.91	.19	8.67	.59	1.49
RAC-S	347.0	91.0	146.	11.9	13.5	.44	52.9	5.76	.44	1.07	.79	.07	3.19	.24	.69
GII-W	453.2	154.	199.	7.7	7.0	.25	23.6	6.13	.42	1.34	1.01	.08	6.85	.43	1.61

° single point test
* subisokinetic sampling - emission data unrepresentative
+ test stopped after 141 min.
** obtained in south quadrant at a single point
++ calculated from #4 and #5

TABLE 4: INCO 381 m CHIMNEY - 1980 SINGLE/MULTIPOINT TESTING

STACK SAMPLING PARAMETERS - PARTICLE SIZING TESTS

Test and Date	Stack Gas Velocity m/s	Stack Gas Temperature °C	Stack Gas Flow Rate DSCMM	% Readings Within ± 10% Isokinetic	% Readings Within ± 15 Isokinetic	Mean Isokinetic Value %
AND #1 30/1/80	14.9	117.	95000	60	92	109.6
BALSTON #1 30/1/80	14.9	117.	95000	24	96	110.3
AND #2 1/2/80	16.7	128.	103000	85	100	104.6
BALSTON #2 1/2/80	16.7	128.	103000	100	100	103.1
AND #3 2/2/80	14.8	125.	91960	95	100	101.
BALSTON #3	14.8	125.	91960	65	80	107.

TABLE 5: PARTICLE SIZING TESTS

PARTICULATE EMISSION CONCENTRATION AND RATE

ANDERSEN IMPACTOR AND BALSTON FILTER

INCO 381 m CHIMNEY - 1980 TEST PROGRAM

Test & Date	Part. Conc. g/std m^3	Part. Emiss. g/s	MMD um
AND #1	.305	483.	6.4
BALSTON #1 & 30/1/80	.816	1290.	
AND #2	.367	632.	3.3
BALSTON #2 & 1/2/80	.586	1020.	
AND #3	.671	1030.	6.4
BALSTON #3 & 2/2/80	.594	907.	

TABLE 6: INCO 381 m CHIMNEY - 1980 SOURCE TESTING PROGRAM

SAMPLING DATA - PARTICLE SIZING TEST #1

Stage	Weight (mg)	Cut Point (um)	% (weight)	% (cumulative weight)
Nozzle & Inlet	123.2			
0	42.5	13.7	36.7	63.3
1	39.0	8.6	8.6	54.7
2	36.3	5.8	8.0	46.7
3	29.9	4.0	6.6	40.1
4	28.4	2.5	6.3	33.8
5	30.7	1.3	6.8	27.0
6	36.5	.79	8.1	18.9
7	38.8	.54	8.6	10.3
Filter	46.2		10.2	-
TOTAL	451.5			

TABLE 7: INCO 381 m CHIMNEY - 1980 SOURCE TESTING PROGRAM

SAMPLING DATA: PARTICLE SIZING TEST #2

Stage	Weight (mg)	Cut-Point (um)	% (weight)	% (cumulative weight)
Nozzle & Inlet	36.6			
0	28.2	13.7	22.6	77.4
1	22.2	8.6	7.7	69.7
2	23.5	5.8	8.2	61.5
3	19.3	4.0	6.7	54.8
4	22.4	2.5	7.8	47.0
5	25.1	1.3	8.7	38.3
6	36.8	.79	12.8	25.5
7	36.1	.54	12.6	12.8
Filter	36.8		12.8	-
TOTAL	287.0			

TABLE 8: INCO 381 m CHIMNEY - 1980 SOURCE TESTING PROGRAM

SAMPLING DATA: PARTICLE SIZING TEST #3

Stage	Weight (mg)	Cut Point (um)	% (weight)	% (cumulative weight)
Nozzle & Inlet	69.6 + 19.8*			
0	22.9	13.7	39.1	60.9
1	23.5	8.6	8.2	52.7
2	29.2	5.8	10.2	42.5
3	19.9	4.0	6.9	35.6
4	17.0	2.5	5.9	29.7
5	17.2	1.3	6.0	23.7
6	18.2	.79	6.3	17.4
7	22.9	.54	8.0	9.3
Filter	26.8		9.3	-
TOTAL	287.0			

* Adjusted by amount caught in internal catch in previous tests.

TABLE 9: INCO 1980 381 m CHIMNEY SAMPLING PROGRAM

PARTICLE SIZING DATA - NORTH QUADRANT

INDIVIDUAL SPECIES

	Cd	Cu	Fe	Mn	Ni	Pb	Zn	Al	Total Part.	SO_4	As
					Emission Concentration - (for comparison only) mg/SCM						
Test #1	.308	9.97	26.6	.139	7.21	6.25	1.08	1.07	305.	186. (46 ppm)	1.02
Test #2	.268	4.06	11.4	.045	2.75	4.53	.754	.90	366.	147.4 (36. ppm)	.92
Test #3	.170	4.06	23.9	.086	5.91	2.41	.593	1.36	673.	151. (36 ppm)	.54
x	.249	6.03	20.6	.09	5.29	4.4	.81	1.11	448.	161.	.83
s.d.	.07	3.41	8.1	.05	2.29	1.92	.25	.23	197.	21.3	.25
					Emission Rate (for comparison only) g/s						
Test #1	.49	15.8	42.1	.22	11.4	9.90	1.71	1.69	483.	295.	1.61
Test #2	.45	6.97	19.6	.082	4.72	7.78	1.29	1.55	632.	253.	1.58
Test #3	.26	6.22	36.8	.132	9.06	3.69	.91	2.08	1029.0	232.	.83
1977 Mean[o]	.318	11.42	39.4	.08	9.22	4.9	2.96	2.54	355		-

TABLE 10: INCO 381 m CHIMNEY - 1980 TESTING PROGRAM

PROCESS DATA SUMMARY FOR THE NICKEL CIRCUIT

Test-Date & Time	# Roasters*	# Reverb**	Total Concentrate[1] to Roasters	Reverb Slag to Dump	NICKEL CONVERTERS*** #	Blowing Time (min)	Matte Production[2] (tonnes)	Reverb Charge[2] (tonnes)	Misc. Charge[2] (tonnes)	Slag to Ni Reverb[2] (tonnes)
Test #1, 31/1/80 11:35 - 14:35	20	3	4036	590	8	544	299	580	108	600
Test #2, 5/2/80 10:00 - 13:00	14	3	4127	590	7	392	281	544	82.5	544
Test #3, 7/2/80 9:45 - 12:45	14	3	4290	635	6	310	315	612	76	544
Test #4, 8/2/80 10:45 - 13:45	15	3	4500	952	8	521	263	569	107	580
Test #5, 11/2/80 11:00 - 14:00	13	3	4255	498	9	499	356	725	84	707

1 24 hour basis
2 8 hour basis

* serviced by Cottrell #1
** serviced by Cottrell #4
*** serviced by Cottrells #2 and #5.

TABLE 10 (CONT.): INCO 381 m CHIMNEY - 1980 TESTING PROGRAM

PROCESS DATA FOR THE COPPER CIRCUIT

Test - Date & Time	Copper Flash Furnace Feed[2] (tonnes)	Copper Converters* #	Blowtime (min)	Blister Cu Production[1] (tonnes)	Fluid Bed Roasters** #	Feed[1] (tonnes)	Part Conc. ($g/std.\ m^3$) mean	range
Test #1, 31/1/80 11:35 - 14:35	382	5	362	399	2	400		
Test #2, 5/2/80 10:00 - 13:00	DOWN	3	117	154	2	438	.42°	.40-.44°
Test #3, 7/2/80 09:45 - 12:45	98	5	339	571	2	639	.533°	.48-.59°
Test #4, 8/2/80 10:45 - 13:45	370	5	311	467	2	541	.31	.19-.40
Test #5, 11/2/80 11:00 - 14:00	292	5	314	476	-		.30	.25-.35

1 24 hour basis
2 8 hour basis
o based on 2 MOE tests

* Serviced by Cottrell #3
** Serviced by Fluid Bed Roaster Cottrells

TABLE II: COTTRELL PRECIPITATOR DATA - INCO 381 m CHIMNEY

1980 SAMPLING PROGRAM

Test, Date & Time	Precipitator Recovery Dust MTPD					Efficiency %					Estimated Particulate Emission MTPD					MTPD (g/s)
	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5	
#1, 31/1/80 1135 - 1435	178	5.7	35	37	3.	99.5		96.1	92.8	94.5	.9	5.5	1.4	2.9	.2	10.9 (126)
#2, 5/2/80 1000 - 1300	219	6.3	33.	25	3	97.4	51.2	90	98.3	95.7	5.9	6.0	3.7	.44	.14	16.1 (186.)
#3, 7/2/80 0945 - 1245	219	6.3	33.	25	3	97.4	51.2	90	98.3	95.7	5.9	6.0	3.7	.44	.14	16.1 (186.)
#4, 8/2/80 1045 - 1345	219	6.3	33.	25	3	97.4	51.2	90	98.3	95.7	5.9	6.0	3.7	.44	.14	16.1 (186.)
#5, 11/2/80 1100 - 1400	224	9.3	31	35	3	97.3	71.0	84.0	98.7	97.2	6.21	3.8	5.8	.46	.1	16.4 (190)

Cotrell Electrostatic Precipitators #1 - Hershoff Roasters#4 - Reverberatory Furnace #2 - Nickel Convertors #2 - 10#5 - 1, 3 Stretched Nickel Convertors #3 - Copper Circuit

TABLE 12: COPPER CLIFF SMELTER

TYPICAL COTTRELL DUST COMPOSITIONS

Material	ANALYSIS % Ni	Fe	Cu	Pb	As	Zn	Bi	Cd	SO_4
No.1 Cottrell Dust Hershoff Roaster	4.48	23.9	2.25	.12	.041	.14	.012	.008	4.5
No.2 Cottrell Dust Ni Convertors	11.5	25.3	9.50	.49	.082	.10	.031	.020	2.4
No.3 Cottrell Dust* Cu Ciruit & 4 Nickel Converters	2.98	14.1	26.0	.66	.100	.57	.10	.090	8.9
No.4 Cottrell Dust Reverberatory	5.25	34.9	2.25	.33	.097	.31	.024	.027	2.0
No.5 Cottrell Dust 3 Stretched Ni Converters	9.15	10.2	14.3	5.00	.48	.87	.35	.032	9.5

* July 5, 1976 - INCO Program Submission

TABLE 13: COMPARISON OF EMISSION RATES DETERMINED FROM PRECIPITATOR OPERATING ESTIMATES AND FROM SOURCE TESTING EMISSIONS - TRACE ELEMENTS - GRAMS/SECOND

Element	Cotrell Precipitator Number #1	#2	#3	#4	#5	Total	Source Sampling Mean Value
Test #1							
Cu	.25	1.67	4.2	.6	.1	6.9	4.2
Ni	.43	2.9	.5	.1	.01	3.9	1.9
Fe	3.3	11.	.2	13.	.6	28.	8.5
Test #2							
Cu	1.6	2.6	11.	.01	.01	15.3	12.7
Ni	2.8	4.4	1.3	.01	.1	8.6	23.4
Fe	22.	17.	6.	1.9	.4	47.	70.5
Test #5							
Cu	1.7	1.6	9.4	.1	.04	13.	12.3
Ni	2.9	2.8	2.0	.1	.07	8.	14.1
Fe	23.0	11.	17.	2.0	.3	53.	43.8

TABLE 14: APPROXIMATE GAS AND SULFUR DIOXIDE DISTRIBUTION FOR COPPER CLIFF SMELTER SOURCES TO 381 m CHIMNEY

Cotrell	Smelting Unit	Gas Volume SCMM	Temperature °C	Volume % SO_2	Tons/Day SO_2
#1	Herreshoff Roasters	19,700	150	1.0	920
#4	Reverberatory Furnaces	22,700	315	0.5	460
#2, #5	Nickel Converters	29,600	150	1.0	1,260
#3	Matte Processing Fluid Bed Roasters	3,100	260	3.0	320
#3	Copper Flash Furnace	30	816	80.0	140(1)
#3	Copper Converters	11,800	150	1.0	500
	Miscellaneous Process Gas and Inleakage	28,860	15	0.0	0
	TOTAL TO STACK	116,000	150	0.7	3,600

NOTE:

(1) Copper flash furnace SO_2 production averages about 440 TPD. Normally about 300 TPD is converted to liquid SO_2 for sale and, on average, 140 TPD is vented to the chimney system.

(2) Reference: July 5, 1976 - INCO Program Submission - Note that current Control Order should result in lower daily SO_2 emissions.